OPERATIONAL STATUS OF KLYSTRON-MODULATOR SYSTEM FOR PAL 2.5-GEV ELECTRON LINAC *

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Abstract

The klystron-modulator(K&M) system of the Pohang Light Source (PLS) generates high power microwaves for the acceleration of 2.5 GeV electron beams. There are 12 modules of K&M system to accelerate electron beams up to 2.5 GeV nominal beam energy. One module of the K&M system consists of a 200 MW modulator and an 80 MW S-band (2856 MHZ) klystron tube. The total accumulated high-voltage run-time of the oldest unit among the 12 K&M systems has reached nearly 88,000 hours as of Dec. 2005. The overall system availability is well over 95%. In this paper, we review overall system performance of the high-power K&M system and the operational status of the klystrons and thyratron lifetimes, and overall system's availability will be analyzed for the period of 1994 to Dec. 2005.

INTRODUCTION

The Pohang Light Source is a third-generation synchrotron radiation facility composed of an injector Linac and a storage ring. The klystron-modulator(K&M) system of PLS Linac had been supplying high power microwaves for the acceleration of 2 GeV electron beams from 1994 to 2002. A 2.5 GeV full energy electron injection has been launched since on October 2002. The 2.5 GeV full energy electron beam from the linac is transported through a beam transfer line (BTL) to the storage ring. Total 12 units of high power klystron-modulator (K&M) systems are under continuous operation in the PAL linac. The peak powers of the modulator and the klystron are 200 MW and 80 MW, respectively. The klystron output frequency is 2856 MHz. Each klystron output is compressed with a SLED and supplied to four of three-meter long accelerating columns. The linac has been operated as a full energy injector for the PAL since December 1994. Annual operation hour of the K&M system is about 7,000 hours

KLYSTRON AND MODULATOR

To satisfy PAL linac design requirements for peak power and maintainability, E3712 S-band klystron tube has been selected as a main microwave source. The tube is manufactured by Toshiba in Japan and SLAC in USA. A SLAC 5045 (65 MW peak) klystron is used for the preinjection module and the following eleven klystrons are Toshiba E3712. The 200 MW modulator for the klystron tube is designed and manufactured inhouse by Pohang Accelerator Laboratory.

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Klystron

Operational parameters of the Toshiba E3712 and SLAC 5045 klystron tube are listed in Table 1. The klystrons have two output ceramic windows to accommodate 80 MW and 60 MW peak power, respectively. The two outputs are combined after the window by a power combiner. The microwave power is compressed with a SLED to enhance accelerating field in the accelerating columns. Maximum accelerating field gradient of linac is 17 MV/m [2].

Table 1: Parameter of Klystron

Parameter	Toshiba E3712	SLAC 5045
Frequency	2,856 MHz	2,856 MHz
Pulse Width	4 μs	3.5 μs
Repetition Rate	60 Hz	180 Hz
Beam Voltage	400 kV	350 kV
Beam Current	500 A	420 A
μ -perveance	2.0	2.0
RF Output Power	84 MW	60 MW
Drive Power	500 W	600 W
Gain	53 dB	49 dB
Efficiency	42 %	40 %

Modulator

The specifications of the modulator are listed in Table 2. Maximum repetition rate of the modulator is 180 Hz as given in Table 1. However, the normal operating rate is 30 Hz. The injection rate of the electron beam to the PAL storage ring is further reduced 10 Hz. Fig. 1 shows a simplified modulator circuit. The modulator can be divided into four major sections: a charging section, a discharging section, a pulse transformer tank, and a klystron load. In the charging section, a SCR AC-AC voltage regulator controls primary 3-phase 480 V AC power. The voltage regulator receives feedback signals from the primary AC voltage and the high voltage DC (HVDC) detector as shown in Fig. 1.

Table 2: Modulator Specification

Description	Parameter
Peak Power	200 MW
Average Power	289 kW
	48 kW
Repetion Rate	180 Hz
	30 Hz
Peak Output Voltage	400 kV
Pulse Width(ESW)	7.5 μs
Flat-top Width(,±0.5 %)	4.4 μs
Charging Time	5.75 ms

The closed loop control of the AC-AC voltage regulator ensures stable HVDC output. The maximum HVDC is 25 kV. For the system and personal safety, the interlock has the static and the dynamic modes. The static mode has the interlock of doors, ground hooks, heater PS, flow and temperature of cooling water, over voltage and current, etc. The dynamic mode has an analog signal from the vacuum system and a digital signal of SCR ac over current. The pulse forming network (PFN) is resonantly charged from the HVDC filter capacitor through the charging inductor and diode. Pulse-to-pulse beam voltage regulation is less than ± 0.5% by using the closed loop control of the AC-AC voltage regulator that is SCRs. Two parallel, fourteen sections, type-E Guillemin networks [3] are used for the PFN. The PFN impedance is about 2.8 Ω. Each PFN capacitor has a fixed capacitance of 50 nF, and each PFN inductor can be varied manually up to 4.5 μH. By adjusting inductance of each PFN section, we can precisely tune the flattop of the modulator output voltage pulse. The end of line clipper (EOLC) shown in Fig. 1 removes excessive negative voltage developed after discharge on the PFN capacitors as well as the thyratron.

Two kinds of thyratrons have been installed in the modulator: ITT F-303 and LITTON L-4888. Forced air-cooling is used for the thyratron. Two triaxial cables in parallel are used to make electrical connections between the PFN and the pulse transformer. The pulse transformer has 1:17 turn ratio. Components in the pulse transformer tank are immersed in high voltage insulating mineral oil. The klystron sits on the pulse tank top cover and is connected to the high voltage output of the pulse transformer. The klystron impedance at the primary of the pulse transformer is 2.8 Ω, which matches with the PFN impedance. During fine-tuning of the PFN impedance, we intentionally produced about 5% positive mismatch to extend switch lifetime by reducing anode dissipation in the thyratron [4, 5]

Operation Status

The current status of the klystron tube is given in Table 3. Twelve klystrons have been failed and replaced so far since 1995 when they were installed in the Linac.

Table 3 : Status of The Klystron (as of Dec. 20, 2005)

Mod. No	Tube Type	Tube Serial No.	HTR Run(hr)	Replacement
M01	SLAC5045	622A	18,077	May 21, 03
M02	E3712	21011PLS	74,460	Aug. 12, 95
M03	E3712	64019PLS	9,317	Aug. 3, 04
M04	E3712	64020PLS	0	Dec. 26, 05
M05	E3712	79021PLS	0	Dec. 28, 05
M06	E3712	14012PLS	62,226	Feb. 25, 97
M07	E3712	77016PLS	16,663	Aug. 4, 03
M08	E3712	82013PLS	61,577	Mar. 28, 97
M09	E3712	96014PLS	19,838	Mar. 7, 03
M10	E3712	40018PLS	15,880	Oct. 17, 03
M11	E3712	65017PLS	16,693	Aug. 20, 03
M12	E3712	65008PLS/R	28,786	Dec. 26, 01

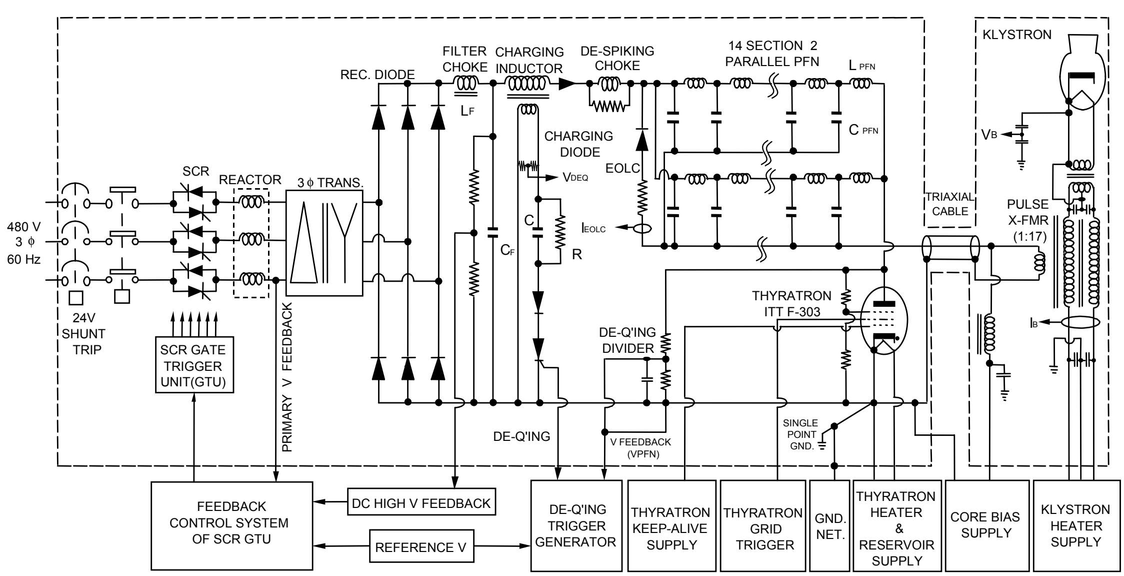

Figure 1: Schematic circuit diagram of the modulator.

The average heater run time of the failure klystron is about 59,700 hr. So far, all of the 12 stations have suffered one failure. The klystron that has the longest operation is the one in station number 4, and its high voltage run time reaches more than 88,000 hours as of December 2005. Failure modes for the twelve failed klystrons were all different kind. The klystron in the station 2 had damage of an electrode due to a focusing electromagnet shortage. The klystron in the station 6 showed bad internal vacuum and caused frequent internal arcing. Heater shortage occurred in the station 8 klystron. And others are heater out of run time. The warranted lifetime of E3712 is 10,000 hours. However, the data listed clearly show that the real lifetime is much longer than the warranted lifetime. The klystron is very costly, and replacement of the klystron requires for a long shutdown time. Therefore, prediction of the klystron lifetime is important for the linac budget and maintenance schedule. But the data collected in the PLS linac are not enough to get a statistical lifetime which can be used for a reference. In our maintenance plan, we are preparing spare klystrons expecting that the average lifetime will exceed over 59,000 hours.

The static and dynamic fault analysis of the K&M system during the period of January to December of 2005 is shown in Fig. 2 and Fig. 3. From Fig. 2, the OCR trip has the highest static fault count because the heater of the thyratron is long operation.

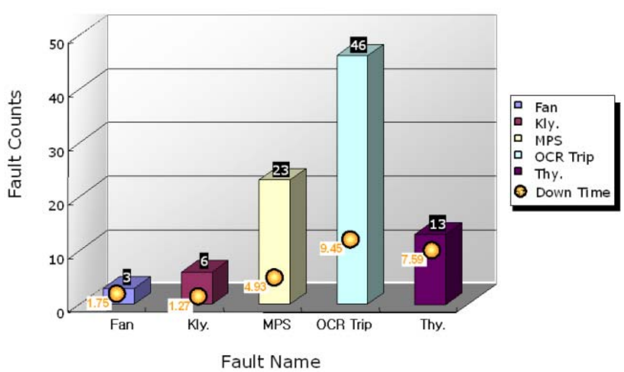

Figure 2: Static fault analysis of the klystron and modulator system (from January to December 20, 2005)

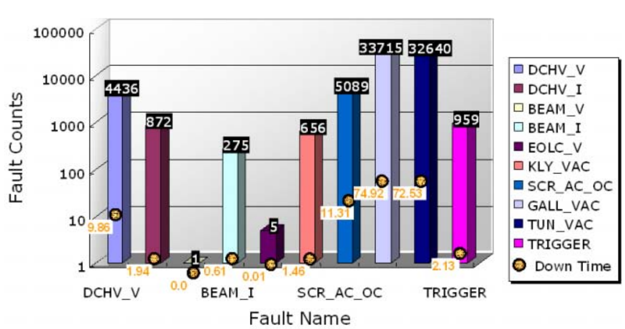

Figure 3: Dynamic fault analysis of the klystron and modulator system (from January to December 20, 2005)

In Fig. 3, the DCHV over-voltage and SCR ac over-current was caused by thyratron misfire due to misleading timing signals and electronic circuit malfunction due to electrical noises. The availability, down time, and fault count of modulator is shown in Fig. 4 during 1994 to 2005. In Fig. 4, we can see the availability reaches about 99.0 % in 2005. We are trying to further reduce the system failure in both dynamic and static count.

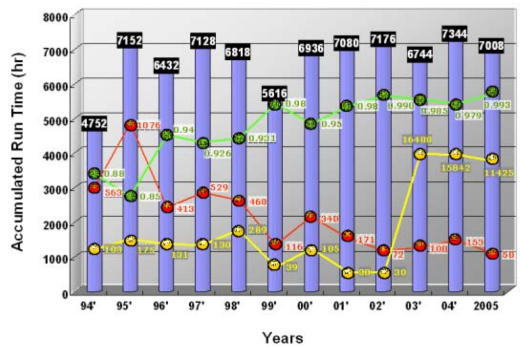

Figure 4: Availability, down time, and fault count of modulator during 1994 to 2005

SUMMARY

The K&M system is a key unit among linac facilities. PAL linac has 12 units of S-band K&M system. Since the K&M system started its full operation in 1994, the longest lived klystron has accumulated over 88,000 hours operation time without failure as of December 2005. Fault and availability analysis of the K&M system shows that the system is running under a stable and reliable condition. The performance of the system has been continuously improved in self-diagnostics, remote operation, remote monitoring, and remote communication. We reviewed overall system performance of the high-power K&M system with accumulated operational dasta from 1994 to December 2005.

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